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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR § 1.53(b))

Attorney Docket No.	*1875.0160000/RES/JTH*
First Inventor or Application Identifier	*Erlend Olson*
Title	*Direct Conversion Tuner*
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. ☐ * Fee Transmittal Form (*e.g.*, PTO/SB/17)
(Submit an original, and a duplicate for fee processing)

2. ☒ Specification [Total Pages 32]
(preferred arrangement set forth below)
- Descriptive title of the Invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings *(if filed)*
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 19]

4. ☐ Oath or Declaration [Total Pages _____]
a. ☐ Newly executed (original or copy)
b. ☐ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 17 completed)* ***[Note Box 5 below]***
i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR §§ 1.63(d)(2) and 1.33(b).

5. ☐ Incorporation By Reference *(useable if Box 4b is checked)*
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. ☐ Microfiche Computer Program *(Appendix)*

7. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
a. ☐ Computer Readable Copy
b. ☐ Paper Copy (identical to computer copy)
c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. ☐ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(b) Statement ☐ Power of Attorney (when there is an assignee)
10 ☐ English Translation Document *(if applicable)*
11. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
12 ☐ Preliminary Amendment
13. ☒ Two (2) Return Receipt Postcards (MPEP 503) *(Should be specifically itemized)*
14. ☐ *Small Entity Statement(s) *(PTO/SB/09-12)* ☐ Statement filed in prior application, Status still proper and desired
15 ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☒ Other. 37 C.F.R. § 1 136(a)(3) Authorization
☐ Other:

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17. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment:*

☐ Continuation ☐ Divisional ☐ Continuation-in-Part (CIP) of prior application No: ____/_____

Prior application information: *Examiner* _____ *Group/Art Unit:* _____

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Commissioner for Patents
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Box Patent Application

Re: U.S. Non-Provisional Utility Patent Application under 37 C.F.R. § 1.53(b)
Appl. No. To be Assigned; Filed: September 18, 2000
For: **Direct Conversion Tuner**
Inventor: Erlend Olson
Our Ref: 1875.0160000/RES/JTH

Sir:

The following documents are forwarded herewith for appropriate action by the U.S. Patent and Trademark Office:

1. USPTO Utility Patent Application Transmittal Form PTO/SB/05;

2. New U.S. Utility Patent Application entitled:

Direct Conversion Tuner

and naming as inventor:

Erlend Olson

the application comprising:

a. specification containing:

i. 22 pages of description prior to the claims;

ii. 9 pages of claims (1-55 claims);

iii. a one (1) page abstract;

b. 19 sheets of drawings: (Figures 1A-1B, 2, 3A-3B, 4-5, 6A-6B, 7-9, 10A-10B, 11-13, 14A-14B, 15-16);

3. 37 C.F.R. § 1.136(a)(3) Authorization to Treat a Reply As Incorporating An Extension of Time; and

4. Two (2) return postcards.

It is respectfully requested that, of the two attached postcards, one be stamped with the filing date of these documents and returned to our courier, and the other, prepaid postcard, be stamped with the filing date and unofficial application number and returned as soon as possible.

This patent application is being submitted under 37 C.F.R. § 1.53(b) without Declaration and without filing fee.

Respectfully submitted,

STERNE, KESSLER, GOLDSTEIN & FOX P.L.L.C.

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JTH/slw
Enclosures

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Direct Conversion Tuner

Inventor(s):
Erlend Olson

Background of the Invention

Field of the Invention

The present invention generally relates to television tuner circuits, and more specifically to a direct conversion television tuner for processing broadcast, cable, and satellite television signals.

Related Art

Television signals are transmitted at radio frequencies (RF) using terrestrial, cable, or satellite transmission schemes. Terrestrial and cable TV signals are typically transmitted at frequencies of approximately 57 to 860 MHZ, with 6 MHZ channel spacings. Satellite TV signals are typically transmitted at frequencies of approximately 980 to 2180 MHz.

Regardless of the transmission scheme, a tuner is utilized to down-convert the received RF signal to an intermediate frequency (IF) signal or a baseband signal, which is suitable for processing and display on a TV or computer screen. The tuner should provide sufficient image rejection during down-conversion as is necessary for the specific application. The National Television Standards Committee (NTSC) sets standards for television signal transmission, reception, and display. To process a NTSC signal, it is preferable that the tuner have a high-level of image rejection. However, less image rejection is acceptable depending on the specific application and the corresponding display requirements.

To achieve a high level of image rejection, traditional TV tuners utilize a dual-conversion architecture having two mixers and a surface acoustic wave

(SAW) filter. The first mixer up-converts the received RF signal to a first IF frequency (e.g. 1200 MHZ) that is fixed above the RF signal band, using a variable local oscillator (LO) signal. A SAW filter, centered at the first IF, selects the channel of interest and provides the necessary image rejection to prevent signal interference. The second mixer then down-converts the first IF to a lower frequency second IF, using a second fixed frequency LO signal. The second IF output is at baseband for a NTSC compatible signal. Alternatively, the second IF is at 36 or 44 MHZ for a cable system output that is fed into a set-top box or a cable modem. Channel selection is realized by adjusting the first LO signal so that the desired down-converted channel(s) falls in the narrow passband of the SAW filter. The remaining channels are rejected by the SAW filter.

Due to advances in silicon integrated circuit (IC) technology, most of the tuner components (i.e. mixers, local oscillators, etc.) can be fabricated on a single silicon IC, with the exception of the SAW filter. The SAW filter is a mechanically resonant device that is typically fabricated on a ceramic substrate, and therefore cannot be integrated on-chip with the other tuner components. As such, the SAW device remains a discrete component in the TV tuner design, which prevents the TV tuner from being fabricated on a single silicon substrate.

A single chip solution is highly desirable for TV tuners and cable modems. The single chip solution will reduce or eliminate component adjustment during manufacturing, and therefore lead to a reduction in manufacturing time and cost. The single chip solution will likely improve electrical performance of the tuner because there are parasitics associated with driving a signal off-chip for processing. Additionally, the single chip solution will reduce the size of the tuners, which becomes more critical for non-TV set applications. Therefore, what is required is a TV tuner architecture that can be implemented on a single semiconductor substrate.

Furthermore, a TV tuner with low power requirements is also desired. Cable TV operators plan to offer voice telephone service and/or Internet access to their customers over currently installed cable lines. The telephone traffic will be

transmitted over the cable lines at RF frequencies, along with the TV programming. As such, the TV tuner will likely be utilized to down-convert the telephone traffic to baseband for user consumption. In the current POTS (plain old telephone service) system, government regulations require that the phone companies supply sufficient power over telephone lines to operate the customer's telephone. This allows the customer to utilize the telephone during a power outage, to call the electric company for example. If a similar requirement were placed on voice-over-cable service, then the cable company would have to supply enough power over the cable lines to operate the TV tuner.

The conventional dual conversion tuner architecture requires a few watts of power for operation, which is a relatively high power requirement. The high power drain occurs because the dual conversion scheme requires two mixers that are driven by two local oscillators operating at RF frequencies. If voice-over-cable is to be realizable, then the tuner power requirements should be reduced to approximately 0.5 watt of power dissipation.

Therefore, what is needed is a tuner architecture that has good electrical characteristics (e.g. high image rejection, and good linearity), low power requirements, and which can be implemented on a single semiconductor substrate.

Summary of the Invention

The present invention is directed to a direct conversion television tuner for processing television or cable signals. The direct conversion television tuner down-converts a selected channel directly from an RF frequency to an IF frequency and/or baseband, without performing an intermediate up-conversion frequency translation as in conventional tuners.

The direct conversion TV tuner includes a pre-select filter, an amplifier, an image reject mixer, and an IF filter. The pre-select filter receives an RF signal having multiple TV channels. The image reject mixer down-converts a selected channel to an IF frequency that is within the passband of the IF filter. Channel

selection is performed by tuning the frequency of a local oscillator signal that drives the image reject mixer, and thereby tuning the channel that is translated into the passband of the IF filter. The frequency of the IF output signal is flexible, and can be set so it is compatible with conventional set-top box and cable modem applications. Additionally, the IF output signal can be converted to a digital format using an A/D converter. In embodiments, the IF output signal is further processed to generate a NTSC compatible signal that can directly drive a television set without any further processing.

In embodiments, the pre-select filter, amplifier, and the image reject mixer are individually calibrated to improve image rejection at the selected channel frequency. The calibration is performed by injecting a test signal into the tuner input, where the frequency of the test signal is at the selected channel frequency. After which, the I/Q balance of the pre-filter is separately determined based on the test signal, bypassing the effects of the amplifier and the image reject mixer. Any I/Q imbalance in the pre-select filter is corrected by adjusting filter parameters. Once the filter is calibrated, the I/Q balance of the amplifier is determined based on the test signal input, bypassing the effects of the image reject mixer. Any I/Q imbalance in the amplifier is corrected by adjusting the amplifier parameters. Once the amplifier is calibrated, the I/Q balance of the image reject mixer is determined based on the test signal input. Any I/Q imbalance in the image reject mixer is corrected by adjusting parameters of the image reject mixer, and/or by adjusting the I/Q balance of the local oscillator that drives the image reject mixer.

The calibration procedure can be repeated for each new channel selection to compensate for I/Q imbalances that vary over frequency. Additionally, the calibration procedure can be repeated for the same channel after a defined time delay to compensate for temperature effects or other miscellaneous time sensitive effects. The result of the calibration procedure is that tuner image rejection preferably meets or exceeds corresponding requirements over the input frequency band of interest.

An advantage of the present invention is that the direct conversion tuner

has a single conversion architecture. More specifically, the selected TV channel is directly down-converted to an IF frequency in a single frequency translation by the image reject mixer. In contrast, conventional tuners have a dual conversion architecture, which performs two frequency translations (one up-conversion and one down-conversion), along with off-chip filtering. The direct conversion tuner has lower power requirements because the single frequency conversion only requires one high frequency local oscillator and one mixer, compared with two of each for the conventional dual conversion tuner.

Additionally, the direct conversion tuner can be fabricated on a single semiconductor substrate, which does not require any off-chip filtering. This is possible because the calibrated image reject mixer provides high image rejection, without using an off-chip SAW filter. As a result, the direct conversion tuner enables a single-chip solution for TV tuner and cable modem applications.

Further features and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with reference to the accompanying drawings.

Brief Description of the Drawings

The present invention is described with reference to the accompanying drawings. In the drawings, like reference numbers indicate identical or functionally similar elements. Additionally, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears.

FIG. 1A illustrates a terrestrial analog TV environment;

FIG. 1B illustrates a frequency spectrum of a NTSC baseband signal;

FIG. 2 illustrates a terrestrial digital TV environment;

FIG. 3A illustrates an analog cable TV environment;

FIG. 3B illustrates the frequency spectrum of an analog IF signal compared to the frequency spectrum of a NTSC signal;

FIG. 4 illustrates a digital cable TV environment having telephone service

and Internet access;

FIG. 5 illustrates a satellite TV environment;

FIG. 6A illustrates a tuner having a mixer and a low pass filter to demonstrate image rejection;

FIG. 6B illustrates a frequency spectrum that illustrates down-conversion and image frequencies;

FIG. 7 illustrates a conventional dual conversion tuner;

FIG. 8 illustrates a direct conversion tuner according to embodiments of the invention;

FIG. 9 illustrates a flowchart associated with the direct conversion tuner in FIG. 8, according to embodiments of the invention;

FIG. 10A illustrates a table of LO frequencies associated with a 36 MHZ IF produced by single step down-conversion, according to embodiments of the invention;

FIG. 10B illustrates a table of LO frequencies associated with a 44 MHZ IF produced by single step down-conversion, according to embodiments of the invention;

FIG. 11 illustrates an image reject mixer according to embodiments of the invention;

FIG. 12 illustrates a flowchart for calibrating the tuner according to embodiments of the present invention;

FIG. 13 illustrates a direct conversion tuner, which can be calibrated to improve image rejection according to embodiments of the invention;

FIGS. 14A-B illustrate a flowchart for calibrating the tuner in FIG. 14 according to embodiments of the invention;

FIG. 15 illustrates a flowchart for calibrating an image reject mixer, according to embodiments of the invention; and

FIG. 16 illustrates a post IF processing module for generating a NTSC output signal, according to embodiments of the invention.

Detailed Description of the Embodiments

1. Terrestrial, Cable, and TV Satellite Services

Television signals are transmitted at radio frequencies (RF) using terrestrial, cable, or satellite transmission schemes. Terrestrial and cable TV signals are typically transmitted at frequencies of approximately 57 to 860 MHZ, with 6 MHZ channel spacings. Satellite TV signals are typically transmitted at frequencies of approximately 980 to 2180 MHz. Regardless of the transmission scheme, a tuner is utilized to down-convert the received RF signal to an IF signal or a baseband signal, which is suitable for processing and display on a TV or computer screen. The desired tuner output can vary depending on the specific transmission scheme, as described below.

Terrestrial TV service is transmitted over the air from ground-based (as opposed to satellite-based) antennas. Terrestrial TV service can be subdivided into conventional analog TV and digital TV (including DTV and HDTV).

FIG. 1A illustrates a conventional analog TV environment 100 having a TV tuner 106 that receives an RF TV signal 102 from an antenna 104. RF TV signal 102 carriers conventional analog TV programming. The analog tuner 106 down-converts the TV signal 102 to a NTSC compatible signal 108. NTSC stands for National Television Standards Committee, and the NTSC standard specifies the parameters for a baseband TV video/audio signal that drives a conventional raster TV monitor. As such, the NTSC baseband signal 108 can be directly coupled to the TV monitor 110. FIG. 1B illustrate the frequency spectrum of a NTSC signal 108. As shown, the NTSC signal 108 has a frequency spectrum at baseband with a 6 MHZ bandwidth.

FIG. 2 illustrates a digital TV environment 200 having an antenna 204, a tuner 206, a digital processor 208, and a TV monitor 210. The antenna 204 receives a digital TV signal 202, which can be a high definition TV signal (HDTV), for example. The tuner 206 down-converts the signal 202 to an

intermediate frequency (IF) signal 207. The processor 208 further processes the IF signal 207, for display on the TV monitor 210. In embodiments, the processor 208 converts the IF signal 207 to a NTSC compatible signal to drive the TV monitor 210.

Cable TV service is carried to the customer using coaxial cables (or the equivalent), where the cables are typically buried underground. Traditional cable TV carries analog TV programming. Modern cable TV service can include digital cable TV, Internet access, and even telephone service. The telephone service is typically provided using a packet-based communications protocol, such as Internet protocol (IP).

FIG. 3A illustrates an analog cable TV environment 300 including a cable 302, a set top box 305 having a tuner 306 and a set-top box processor 310, and a TV monitor 312. The cable 302 carries a cable signal 304 having analog cable TV programming. The tuner 306 down-converts the cable signal 304 to produce an analog IF signal 308 carrying analog TV signals, and a NTSC signal 309. The NTSC signal 309 exists at baseband and can be routed directly to the TV monitor 312 as described above. The analog IF signal 308 carries additional TV features (e.g. on-screen program information) that are not carried by the NTSC signal 309. The analog IF signal 308 is sent to the set-top processor 310 for further processing in order to generate a signal suitable to drive the TV monitor 312.

For comparison purposes, FIG. 3B illustrates the frequency spectrum of the analog IF signal 308 and the NTSC signal 309. As described above, the NTSC signal has a 6 MHZ bandwidth at baseband. The analog IF signal 308 has a 6-8 MHZ bandwidth at 36 MHZ, or 44 MHZ, or some other useful IF frequency. In other words, the IF frequency of the signal 308 can be selected so as to be compatible with the processor 310. In embodiments, the IF signal 308 is modulated according to quadrature amplitude modulation (QAM), which is a multi-level multibit signal format that is well known to those skilled in the arts.

FIG.4 illustrates a digital cable TV environment 400 having a cable 402, a tuner 406, a processor 410, a telephone 412, a computer 414, and a TV monitor

416. The cable 402 carries a cable signal 404 that includes one or more of the following: digital cable TV signals, Internet access, and telephone traffic. The tuner 406 down-converts the cable signal 404 to produce an IF signal 408 carrying digital data, and a NTSC signal 409. The NTSC signal 409 can be sent directly to the TV monitor 416 for display as described above. The digital IF signal 408 carries the digital cable TV, Internet access, and telephone traffic. In embodiments, the digital IF signal 408 is a QAM signal having a bandwidth of 6-8 MHZ and existing at 36 MHZ or 44 MHZ, and having a frequency spectrum that is similar to the frequency spectrum of the analog IF signal 308 (in FIG. 3B).

Still referring to FIG. 4, a processor 410 separates the content of the digital IF signal 408, and provides any necessary post-down-conversion processing. After processing, telephone traffic is sent to the telephone 412, Internet traffic is sent to the computer 414, and TV programming in sent to the TV monitor 416. The digital cable TV signals may be converted to the NTSC format prior to display.

The processor 410 is meant to be a functional representation and is not meant to be limiting. In other words, the processor 410 can include one or more distinct processors to separately process the voice, Internet, and TV programming signals, as per the specific application and signal protocols. When the cable signal 404 is providing Internet access, then the tuner 406 and processor 410 are often referred to as being part of a cable modem, as will be understood by those skilled in the arts.

FIG. 5 illustrates a satellite TV environment 500 having an antenna 504, a satellite tuner 506, a processor 510, and a TV monitor 512. The antenna 504 receives a satellite TV signal 502 and sends it to the tuner 506. The tuner 506 down-converts the signal 502 to an IF signal 508. For most satellite TV systems, the IF signal 508 is a digital signal. The processor 510 further processes the IF signal 508, for display on the TV monitor 512. In embodiments, the processor 510 converts the IF signal 508 to a NTSC compatible signal that drives the TV 512.

To summarize the TV delivery systems in FIGS. 1-5, the tuner output is

either a NTSC signal at baseband, or an IF signal. The NTSC signal can directly drive a TV monitor. The IF signal exists at higher IF frequency (36 or 44 MHZ) and is chosen to be compatible with specific set-top box and/or cable modem devices.

2. *Image Rejection and Linearity*

Image rejection and linearity are two key performance parameters for RF down-conversion. Image rejection and linearity requirements depend on the specific application and the corresponding display requirements. Because of its importance, image rejection is explained further as follows.

FIG. 6A illustrates a tuner 600 having a mixer and low pass filter. The tuner 600 down-converts an RF input 602 to an IF output 604, using a LO input 606. FIG. 6B illustrates an example frequency spectrum 608 that illustrates down-conversion and image rejection as performed by the tuner 600. More specifically, the spectrum 608 illustrates an exemplary RF input 602 having a RF carrier 610 at 800 MHZ, and two RF channels 612, 614 at 794 MHZ and 806 MHZ, respectively. For purposes of illustration, the LO input 606 is set to 800 MHZ so that the RF input 602 is frequency translated to 0 Hz by the tuner 600. More specifically, the RF carrier 602 is translated to 0 Hz to create a DC signal 618. The RF channels 612, 614 are translated to -6 MHZ and +6 MHZ, respectively, resulting in IF signals 616 and 620 as shown. However, negative frequencies are a mathematical convenience, and fold over into the positive frequency domain. Assuming no image rejection, the signal 616 folds on top of the signal 620 as shown. Therefore, without image rejection, channels 612 and 614 interfere with each other during down-conversion, and neither channel is recoverable. Image rejection is calculated as the relative amplitude of the desired image compared to the undesired image. For example, if the channel 614 is the desired channel, then the image rejection of the tuner 600 is the ratio of the signal 620 amplitude compared to the signal 616 amplitude. If tuner 600 had perfect image rejection,

then the amplitude of the signal 616 would be zero.

3. Conventional Tuner

Before describing the invention in detail, it is useful to describe a conventional tuner for purposes of comparison. FIG. 7 illustrates a conventional tuner 700 that is a dual conversion tuner. The tuner 700 performs two frequency translations (one up-conversion, one down-conversion) to meet the high image rejection requirement. The tuner 700 receives a RF signal 701 having multiple TV channels that each have a 6 MHZ bandwidth, and collectively occupy a frequency range of 57-860 MHZ. The tuner 700 down-converts a selected channel from the RF signal 701, and outputs the selected channel as an IF signal 724. In embodiments, the frequency of the IF signal 724 is 36 MHZ, or 44 MHZ, or some other desired IF frequency.

The detailed operation of the conventional tuner 700 is as follows. An RF amplifier 704 amplifies the RF input signal 701 prior to frequency translation. A first mixer 706 mixes the RF input signal 701 with a variable LO signal 708. The LO 710 varies the frequency of the LO signal 708 from 1200 to 2100 MHZ. Therefore, the RF input signal 701 is up-converted to a frequency above the 57-860 MHZ band, resulting in an up-converted signal 707. The up-converted signal 707 is sent off-chip to a SAW filter 712, which has a narrow passband at 1200 MHz. The SAW filter 712 selects a desired channel 713 that falls within its narrow passband, and substantially rejects all of the remaining channels. Therefore, a particular channel is selected by varying the frequency of the LO signal 708 so that the desired channel is up-converted into the passband of the SAW filter 712.

Still referring to FIG. 7, the desired channel 713 is sent back on-chip to a second mixer 714, which is driven by a fixed local oscillator 718. The mixer 714 down-converts the desired channel using a fixed local oscillator signal 716, resulting in an IF signal 715. Given that the SAW filter is centered at 1200 MHZ, the frequency of the LO signal 716 is appropriately selected to provide an IF at 36

MHZ, 44 MHZ, or some other desired IF frequency. The off-chip IF filter 720 further removes any unwanted harmonics and images from the IF signal 715, resulting in the IF signal 721. The IF signal 721 is amplified by the IF amplifier 722, to produce the IF output 724.

The dual conversion architecture of the conventional tuner 700 has several disadvantages. For instance, there are two of each component including two mixers, two high frequency local oscillators, and two off-chip filters. This results in a high DC power requirement (about 3 watts) because each of the two mixers is driven by a separate high frequency local oscillator, where each local oscillator (LO) must generate sufficient power at high frequencies to operate its corresponding mixer. A second disadvantage is that the SAW filter is an off-chip component that prevents a single chip tuner solution, which has inherent manufacturing advantages. Additionally, electrical performance is degraded by taking a high frequency signal off-chip (and back on-chip) because of the inherent parasitics that are involved.

4. Direct Conversion Tuner

FIG. 8 illustrates a direct conversion tuner 800 according to embodiments of the invention. The tuner 800 receives an RF input signal 801 having multiple TV or cable channels, and down-converts the RF input signal 801 to an IF signal 810. In embodiments, the IF signal 810 is at 36 MHZ, or 44 MHZ, which are popular frequencies for set-top box and cable modem devices. The tuner 800 includes a pre-select filter 802, an amplifier 804, an image reject mixer 806, and a polyphase filter 808. In embodiments, all of the mentioned components are on a common semiconductor substrate 814. The detailed operation of the tuner 800 is described in reference to a flowchart 900 that is shown in FIG. 9.

In step 902, the pre-select filter 802 receives the RF input signal 801. In embodiments, the RF input signal 801 includes multiple frequency channels from 57 MHZ to 860 MHZ, with each channel having a 6 MHZ bandwidth.

In step 904, the pre-select filter 802 pre-selects the input frequency band of interest, and rejects out of band signals, producing a RF signal 803. The pre-select filter 802 is a lowpass or bandpass filter having a desired passband of interest. For example, for broadcast or cable TV, the frequency band of interest is approximately 57-860 MHz. For satellite reception, the frequency band can be much higher depending on the specific system that is used.

In step 906, the amplifier 804 amplifies the RF signal 803, resulting in a RF signal 805. In embodiments, the amplifier 804 is a low noise amplifier.

In step 908, the image reject mixer 806 directly down-converts the RF signal 805 to an IF signal 807 having in-phase and quadrature components 807a and 807b, respectively. The image reject mixer 806 mixes the RF input signal 805 with a LO signal 811 that is generated by a variable LO 812. For direct down-conversion, the LO signal 811 is in-band. In other words, the frequency of the LO signal 811 is in the same frequency band as the channels that make-up the RF input signal 801.

In embodiments, the LO 812 is a voltage controlled oscillator (VCO), where the oscillator frequency is controlled by a voltage input. In alternate embodiments, the LO 812 includes one or more phase locked loops.

In step 910, the polyphase filter 808 selects the channel of interest from the component IF signals 807a and 807b, resulting in an output IF signal 810. The polyphase filter 808 has a narrow passband at is the desired IF frequency. For example, the polyphase filter 808 can be fabricated to have a passband centered at 36 or 44 MHZ. Channel selection is performed by changing the frequency of the LO signal 811, and thereby causing the desired channel to shift into the passband of the polyphase filter 808.

FIG. 10A depicts a table 1002 that further illustrates channel selection using the tuner 800, when down-converting to a 36 MHZ IF. More specifically, the table 1002 indicates two LO frequencies that can be used to down-convert specific RF input channels to an IF frequency of 36 MHz. For example, if channel 4 is the desired channel, then the frequency of the LO 812 should be set to 111

MHZ or 39 MHZ. By setting the LO 812 to 111 MHZ or 39 MHZ, then CH 4 will be down-converted to 36 MHZ and is shifted into the passband of the polyphase filter 808. Continuing this example, assuming that the LO is set to 111 MHZ, an unwanted image frequency occurs at 147 MHZ, which is channel 16 in this example. However, this image frequency is not down-converted to the 36 MHZ IF because of the image reject features of the image reject mixer 806.

FIG. 10B illustrates a table 1004 that is similar to the table 1002 except that the LO frequencies are determined for a 44 MHZ IF, instead of a 36 MHZ IF.

In embodiments, the steps 904-908 are performed using differential circuitry that operates on differential signals, as will be understood by those skilled in the arts. In alternate embodiments, the steps 904-908 are performed using single-ended circuitry that operates on single-ended (i.e. non-differential) signals.

4.1 Image Reject Mixer

As shown, the direct conversion TV tuner 800 includes an image reject mixer 806 for down-conversion. The image reject mixer 806 is key to performing the down-conversion operation in a single frequency conversion, instead of the conventional dual-conversion operation. In other words, the image reject feature supplants the need for a dual conversion architecture and the off-chip SAW filter.

FIG. 11 illustrates an image reject mixer 1100 as an embodiment of the image reject mixer 806 in FIG. 8. Image reject mixer 1100 includes an in-phase divider 1102, component mixers 1104a, 1104b, and a quadrature divider 1106. The in-phase divider 1102 receives the RF input signal 805, and divides the signal 805 into component signals 1103a and 1103b, where the signals 1103a and 1103b are substantially equal phase and equal amplitude. The quadrature divider 1106 receives the LO signal 811 and divides the LO signal 811 into component LO signals 1105a and 1105b, where the signal 1105b is phase shifted by 90 degrees relative to the signal 1105a. The mixer 1104a mixes the I component signal 1103a with the LO signal 1105a, resulting in the in-phase IF component 807a. The mixer

1104b mixes the component signal 1103b with the LO signal 1105b, resulting in the quadrature IF component 807b. The in-phase IF component 807a and the quadrature IF component 807b are combined by the polyphase filter 808 (FIG. 8). The image rejection occurs when the I and Q components 807a, 807b are combined because the phase relationship between I and Q components causes signal cancellation at the image frequency.

Theoretically, infinite image rejection is achievable if the I and Q channels of the mixer 1100 are perfectly balanced at the frequency of interest. However, if the phase relationship between the I and Q channels varies from 90 degrees at some frequency, then the actual image rejection deteriorates at this frequency. Additionally, if the amplitude varies between the I and Q channels, then the image rejection also deteriorates. The amplitude and phase relationship between the I and Q channels is often collectively referred to as I/Q balance. Perfect I/Q balance is achieved when the amplitude response of the I and Q channels is equal over frequency, and the phase difference between the I and Q channels is 90 degrees over frequency.

The invention is not limited to the IQ image reject mixer that is shown in FIG. 11. Other image reject mixers can be utilized, as will be understood by those skilled in the arts, including but not limited to passive mixers.

4.2. Tuner Calibration

As discussed above, the actual image rejection that is achieved for an image reject mixer deteriorates if there are amplitude and/or phase errors between the I and Q channels (i.e. I/Q imbalance). More specifically, a small I/Q imbalance over frequency can cause a large variation in the corresponding image rejection. In a high volume manufacturing environment, these amplitude and phase errors can originate from part-to-part variations of electrical parameters that are within stated tolerances of the electrical components. The result is that image rejection can be reduced to below a desired level.

4.2.1 Overview of Tuner Calibration for I/Q Balance

The tuner 800 can be calibrated for each channel frequency to correct for I/Q imbalance, and therefore improve image rejection. The calibration is done by injecting a test signal at the selected channel frequency into the tuner, and adjusting the tuner components to improve I/Q balance, and therefore image rejection. The calibration procedure is described in more detail according to a flowchart 1200 that is shown in FIG. 12.

In step 1202, a new channel selection is received. The selected channel is one of several channels carried by the RF input signal 801. In embodiments, the RF input signal 801 includes multiple channels from 57 MHZ to 860 MHZ, with each channel having a 6 MHZ frequency bandwidth.

In step 1204, the LO 812 generates a test signal 814 at the selected channel frequency. The test signal 814 is injected into the input of the filter 802.

In step 1206, the pre-select filter 802 is calibrated to improve I/Q balance at the frequency of the selected channel.

In step 1208, the amplifier 804 is calibrated to improve I/Q balance at the frequency of the selected channel.

In step 1210, the image reject mixer 806 is calibrated to improve I/Q balance at the frequency of the selected channel. More specifically, regarding phase, the image reject filter 806 is calibrated so that the phase difference between the I and Q channels is as close to 90 degree as possible, so as to maximize image rejection.

In step 1212, the calibration procedure, defined by steps 1204-1210, can be repeated after a pre-defined time delay. The calibration procedure is repeated, even though the channel has not been changed, to compensate for circuit parameter variations that are time sensitive. For instance, electrical characteristics of components may vary over time because of temperature variations, especially at initial power-up.

4.2.2 Detailed Discussion of Tuner Calibration for I/Q Balance

FIG. 13 illustrates tuner 1300, which is a more detailed embodiment of the tuner 800. The tuner 1300 will be utilized to further explore tuner calibration for image rejection, according to embodiments of the present invention. The tuner 1300 includes a bandpass pre-select filter 1304, an amplifier 1306, an I/Q image reject mixer 1310, a local oscillator 1314, and a polyphase filter 1318, which are all similar to the corresponding components in tuner 800. Additionally, the tuner 1300 includes a synthesizer 1312, a signal amplitude and phase analyzer 1316 (hereinafter signal analyzer 1316), a signal processing module 1322, a register/control module 1332, and a local processor 1334, which are discussed further below.

The tuner 1300 operates similar to the tuner 800, but includes some additional features. More specifically, the tuner 1300 receives an RF input signal 1302 having multiple VHF and UHF channels. The tuner 1300 down-converts a selected channel from the RF input signal 1302 to produce an analog IF signal 1320. The analog IF signal 1320 exists at an IF frequency of 36 MHZ, or 44 MHZ, or some other useful frequency, and is compatible with currently available set-top boxes. The down-conversion and channel selection are performed similar to that described for the tuner 800. The signal processing module 1322 also receives the analog IF signal 1320 and converts it into a digital signal 1330 using an A/D converter 1324, a FIR filter 1326, and a MUX 1328.

Additionally, the tuner 1300 can be calibrated to maximize I/Q balance for each new channel selection. The calibration of the tuner 1300 is a three step process, where the filter 1304, the amplifier 1306, and the image reject mixer 1310 are individually calibrated to maximize overall tuner image rejection. The calibration is performed by injecting a test signal at the selected channel frequency into the filter 1304, and then separately examining I/Q balance at the outputs of the filter 1304, amplifier 1306, and the image reject mixer 1310. As described

herein, the maximum image rejection is achieved when there is a balanced amplitude, but a 90 degree phase shift between the I and Q channels. The calibration of the tuner 1300 is described in detail with reference to the flowchart 1400 (FIGs. 14A-B) as follows.

In step 1402, the local processor 1334 receives a channel selection input 1336, which identifies a TV channel that is to be displayed.

In step 1404, the LO 1314 generates a test signal 1338 at the selected channel frequency. The test signal 1338 is injected into the input of the pre-select filter 1304.

In step 1406, the signal analyzer 1316 measures the I/Q balance of the filter 1304, based on the test signal input 1338. More specifically, the switches 1340 are closed so that the filter 1304 output is connected to the signal analyzer 1316, through the test path 1308. As such, the amplifier 1306 and the I/Q mixer 1310 are by-passed so the filter characteristics can be analyzed without being influenced by the amplifier 1306 or the mixer 1310. The signal analyzer measures the amplitude and phase for the I and Q channels at the output of the filter 1304, and determines the I/Q balance between the I and Q channels. As discussed herein, the I/Q balance is the amplitude balance and phase difference between the I and Q channels. The I/Q balance information is forwarded to the processor 1334 for further processing. In embodiments, the signal analyzer incorporates an RF power meter.

In step 1408, the processor 1334 calibrates the filter 1304 to maximize the I/Q balance at the selected channel frequency using a filter calibration signal 1344. More specifically, the parameters of the filter 1304 are adjusted so that the amplitude of the I and Q channels are balanced, and so that the phase difference between the I and Q channels is substantially 90 degrees. In embodiments, the filter parameters that are adjusted include one or more of the following: center frequency, bandwidth, gain, and phase.

In step 1410, the steps 1404-1408 are repeated as necessary to produce sufficient I/Q balance in the filter 1304 at the selected channel frequency.

In step 1412, the LO 1314 re-generates the test signal 1338 at the selected channel frequency, and injects the test signal 1338 into the bandpass filter 1304.

In step 1414, the signal analyzer 1316 measures the I/Q balance of amplifier 1306, based on the test signal input 1338. More specifically, the switches 1340 are opened, and switches 1342 are closed. Therefore, the filter 1304 output is connected to the amplifier 1306 input, and the amplifier 1306 output is connected directly to the signal analyzer 1316, bypassing the image reject mixer 1310. Since the filter 1304 was calibrated in steps 1404-1410, any I/Q imbalance that is measured by the signal analyzer 1316 is likely to be caused by the amplifier 1306. The I/Q balance information for the amplifier 1306 is forwarded to the processor 1334.

In step 1416, the processor 1334 calibrates the amplifier 1306 to maximize the I/Q balance at the selected channel frequency using an amplifier calibration signal 1346. More specifically, the parameters of the amplifier 1306 are adjusted so that the amplitude of the I and Q channels are balanced, and so that the phase difference between the I and Q channels is 90 degrees. In embodiments, the parameters that are adjusted include the gain and phase of the amplifier.

In step 1418, the steps 1412-1416 are repeated as necessary to achieve sufficient I/Q balance in the amplifier 1306 at the selected channel frequency.

In step 1420, the LO 1314 re-generates the test signal 1338 at the selected channel frequency, and injects the test signal 1338 into the bandpass filter 1304.

In step 1422, the signal analyzer 1316 measures the I/Q balance of the image reject mixer 1310. More specifically, the switches 1340 and 1342 are opened so that the test path 1308 is deactivated. Additionally, the switches 1315a and 1315b are closed. Therefore, the filter 1304, amplifier 1306, and I/Q mixer 1310 are connected together, with the mixer 1310 output being connected to the signal analyzer 1316. Since the filter 1304 and amplifier 1306 were calibrated in steps 1404-1418, any I/Q imbalance that is measured by the signal analyzer 1316 is likely to be caused by the image reject mixer 1310.

In step 1424, the processor 1334 calibrates the image reject mixer 1310

to maximize the image rejection at the selected channel frequency. This is a two step process as described by flowchart 1500 in FIG. 15. First, in step 1502, the parameters of the mixer 1310 are adjusted using a mixer cal signal 1348 to get the best the I/Q balance for the mixer 1310 alone. In embodiments, the parameters that are adjusted include the gain and phase of the mixer. Next, in step 1504, the relative phase-shift between the I and Q components of a LO signal 1311 is adjusted to produce the maximum I/Q balance at the output of image reject mixer 1310. In other words, the phase difference between the I and Q components of the LO signal 1311 is varied from 90 degrees to compensate for any residual I/Q imbalance that is left in the mixer 1310 after step 1502.

In step 1426, the steps 1420-1424 are repeated as necessary to produce sufficient I/Q balance at the output of the mixer 1304.

4.2.3 Automatic Frequency Control and Automatic Gain Control

In a terrestrial TV transmission system, the frequency channels of the RF input signal can vary by a few percent from their expected frequency. These frequency errors cause the NTSC signal to be shifted off of baseband, which produces unwanted distortion to appear in the TV picture that is ultimately displayed. The frequency errors stem from inaccuracies in the various TV transmitters that are utilized to transmit the individual TV channels. These inaccuracies are not typically present in cable and satellite transmissions because there is inherently more uniformity in the transmitter equipment that is used for cable and satellite systems.

To address frequency variation in terrestrial systems, conventional TV baseband processors examine the NTSC signal to determine if the NTSC signal is shifted in frequency, which indicates the corresponding RF input signal is also shifted in frequency. If a frequency shift is detected, then an automatic frequency control (AFC) signal is sent to the TV tuner to adjust the frequency of the local

oscillator and thereby compensate for the frequency error in the RF input signal. In other words, the local oscillator frequency is adjusted as necessary to track the frequency error of RF input signal. Referring to the tuner 1300, the local processor 1334 receives an AFC signal 1348 that is utilized to adjust the LO 1314 as needed, to track any frequency errors in the RF input 1302.

Similar to the AFC signal 1348, an automatic gain control (AGC) signal 1350 is received by the processor 1334. The AGC signal 1350 contains gain control information that is used to compensate for amplitude variations of the channels in the RF input signal 1302. For example, one channel in the signal 1302 may be stronger or weaker than the other channels in the signal 1302. Therefore, the gain of amplifier 1306 can be adjusted appropriately to compensate for these amplitude variations.

4.3 Post-IF Processing

The tuner 1300 outputs an analog IF signal 1320 at 36 MHZ, 44 MHZ, or some other IF frequency that is compatible with available set-top box or cable modem devices. However, some cable customers do not want to utilize a set-top box for cost/complexity reasoning. Therefore, it is desirable for the tuner to output a baseband NTSC signal, which can drive a TV monitor without the need for a set-top box.

FIG. 16 illustrates a post processing module 1600 that converts the analog IF signal 1320 to a baseband NTSC output signal 1608. The post processing module 1600 includes an A/D converter 1602, a digital signal processor 1604, and a D/A converter 1606. During operation, the A/D converter 1602 samples and down-converts the analog IF signal 1320 according to a clock signal 1609, to generate a digital signal 1603. In embodiments, the clock signal 1609 is a sub-harmonic clock signal so that the A/D converter 1602 sub-samples the analog IF signal 1320. The DSP 1604 processes the digital signal 1603 to produce a NTSC digital signal 1605. In other words, the NTSC signal 1605 contains the NTSC

information at baseband, but in a digital format, instead of the desired analog format. Finally, the D/A converter 1606 converts the digital signal 1605 to an analog NTSC signal 1608, which can drive a TV monitor.

5. Other Applications

The tuner invention described herein has been discussed in terms of processing broadcast television signals and/or cable signals. However, the invention is not limited to TV applications. The tuner invention is applicable to any application that requires down-conversion of an RF signal to an IF signal and/or a baseband signal, as will be understood by those skilled in the arts. These other applications are within the scope and spirit of the present invention.

6. Conclusion

Example embodiments of the methods, systems, and components of the present invention have been described herein. As noted elsewhere, these example embodiments have been described for illustrative purposes only, and are not limiting. Other embodiments are possible and are covered by the invention. Such other embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

In the Claims:

1. A tuner, comprising:

a pre-select filter that receives a plurality of channels;

an image reject mixer coupled to an output of said pre-select filter;

a local oscillator coupled to said image reject mixer; and

an IF filter coupled to an output of said image reject mixer;

wherein said image reject mixer directly down-converts a selected channel from said plurality of channels to an IF frequency that is within a passband of said IF filter, said selected channel determined by a frequency of said local oscillator.

2. The tuner of claim 1, further comprising a means for adjusting said local oscillator frequency to change said selected channel.

3. The tuner of claim 1, wherein said tuner is on a single semiconductor substrate.

4. The tuner of claim 1, wherein an undesired image of said selected channel is suppressed by said image reject mixer.

5. The tuner of claim 1, wherein said image reject mixer includes two or more component mixers that are driven in quadrature by said local oscillator.

6. The tuner of claim 1, wherein said IF filter is a poly-phase filter.

7. The tuner of claim 1, further comprising a signal processing module coupled to an output of said IF filter, said signal processing module converting an analog IF output signal to a digital IF output signal.

8. The tuner of claim 1, wherein said pre-select filter is calibrated based on

said selected channel, said pre-select filter calibration being independent of said image reject mixer.

9. The tuner of claim 1, wherein said image reject mixer is calibrated based on said selected channel.

10. The tuner of claim 1, further comprising an amplifier coupled between said pre-select filter and said image reject mixer.

11. The tuner of claim 10, wherein said amplifier is calibrated for said selected channel.

12. The tuner of claim 10, further comprising:

a test path having a first input coupled to an output of said pre-select filter, and a second input coupled to an output of said amplifier; and

a signal analyzer having an input coupled to an output of said test path.

13. The tuner of claim 12, wherein said test path bypasses said image reject mixer.

14. The tuner of claim 12, wherein said local oscillator injects a test signal having a frequency of said selected channel into an input of said pre-select filter.

15. The tuner of claim 14, wherein said signal analyzer determines an I/Q balance of said pre-select filter based on said test signal.

16. The tuner of claim 15, wherein parameters of said pre-select filter are adjusted to improve said I/Q balance of said amplifier.

17. The tuner of claim 14, wherein said signal analyzer determines an I/Q

balance of said amplifier based on said test signal.

18. The tuner of claim 17, wherein parameters of said amplifier module are adjusted to improve said I/Q balance of said amplifier.

19. The tuner of claim 14, wherein said signal analyzer has a second input coupled to an output of said image reject mixer, and wherein said signal analyzer determines an I/Q balance of said image reject mixer based on said test signal.

20. The tuner of claim 19, wherein parameters of said image reject mixer are adjusted to improve said I/Q balance of said image reject mixer.

21. The tuner of claim 19, wherein an I/Q balance of said local oscillator is adjusted to improve said I/Q balance of said image reject mixer.

22. The tuner of claim 1, wherein said pre-select filter is a bandpass filter, and wherein a passband of said bandpass filter corresponds to a bandwidth of said plurality of channels.

23. The tuner of claim 1, further comprising a means for compensating for a frequency drift of said RF input signal.

24. The tuner of claim 23, wherein said means for compensating comprises a means for adjusting a frequency of said local oscillator to track said frequency drift of said RF signal, based on an automatic frequency control signal.

25. A tuner, comprising:

a pre-select filter that receives a plurality of channels;

an image reject mixer that directly down-converts said plurality of channels to corresponding lower IF frequencies, said IF frequencies determined by a

frequency of a local oscillator signal; and

an IF filter that selects a channel from said plurality of down-converted channels, wherein said selected channel is in passband of said IF filter.

26. A tuner, comprising:

a pre-select filter that receives a plurality of channels;

an amplifier that is coupled to said pre-select filter;

an image reject mixer that is coupled to said amplifier;

an IF filter coupled to an output of said image reject mixer; and

a test path having a first input coupled to an output of said pre-select filter, and a second input coupled to an output of said amplifier, wherein said test path bypasses said image reject mixer.

27. The tuner of claim 26, further comprising:

means for injecting a test signal into said pre-select filter, wherein said test signal corresponds to a selected channel; and

a signal analyzer, coupled to an output of said test path, wherein said signal analyzer determines an I/Q balance of said pre-select filter based on said test signal.

28. The tuner of claim 27, further comprising means for adjusting parameters of said pre-select filter based on said I/Q balance.

29. The tuner of claim 27, wherein said signal analyzer determines an I/Q balance of said amplifier based said test signal.

30. The tuner of claim 29, further comprising means for adjusting parameters of said amplifier based on said I/Q balance.

31. A method of calibrating a tuner for a selected channel, comprising the

steps of:

(1) generating a test signal having a frequency that corresponds to said selected channel;

(2) injecting said test signal into an input of said tuner; and

(3) determining an I/Q balance of one or more components of the tuner, based on said test signal.

32. The method of claim 31, further comprising the step of:

(4) adjusting parameters of said components of the tuner to improve said I/Q balance.

33. The method of claim 32, further comprising the step of:

(5) repeating steps (1)-(4) after a time delay.

34. The method of claim 31, wherein step (3) comprises the step of determining an I/Q balance of a pre-select filter based on said test signal.

35. The method of claim 34, further comprising the step of:

(4) adjusting one or more parameters of said pre-select filter to improve said I/Q balance of said pre-select filter at said selected channel frequency.

36. The method of claim 31, wherein step (3) comprises the step of determining an I/Q balance of an amplifier based on said test signal.

37. The method of claim 36, further comprising the step of:

(4) adjusting one or more parameters of said amplifier to improve said I/Q balance of said amplifier at said selected channel frequency.

38. The method of claim 31, wherein step (3) comprises the step of

determining an I/Q balance of an image reject mixer based on said test signal.

39. The method of claim 38, further comprising the steps of:

(4) adjusting one or more parameters of said image reject mixer to improve said I/Q balance of said image reject mixer at said selected channel frequency.

40. The method of claim 39, further comprising the step of:

(5) adjusting an I/Q balance of a local oscillator signal that drives said image reject mixer to improve said I/Q balance of said image reject mixer.

41. A method of calibrating a tuner for a selected channel, comprising the steps of:

(1) generating a test signal having a frequency that corresponds to said selected channel;

(2) injecting said test signal into an input of said tuner;

(3) determining an I/Q balance of a pre-select filter based on said test signal; and

(4) adjusting parameters of said pre-select filter to improve said I/Q balance for said pre-select filter at said selected channel frequency.

42. The method of claim 41, further comprising the steps of:

(5) determining an I/Q balance of an amplifier based on said test signal, wherein step (5) is performed after step (4); and

(6) adjusting parameters of said amplifier to improve said I/Q balance for said amplifier at said selected channel frequency.

43. The method of claim 42, further comprising steps of:

(7) determining an I/Q balance of an image reject mixer based on said test signal, wherein step (7) is performed after step (6); and

(8) adjusting parameters of said image reject mixer to improve said I/Q balance for said image reject mixer at said selected channel frequency.

44. The method of claim 43, further comprising the step of:

(9) adjusting an I/Q balance of a local oscillator signal that drives said image reject mixer to improve said I/Q balance of said image reject mixer.

45. In a tuner, a method of processing an RF input signal having a plurality of channels, wherein one of said channels is a selected channel, comprising the steps of:

(1) filtering the RF input signal using an input filter to remove out-of-band signals;

(2) down-converting the RF input signal to a down-converted signal using an image reject mixer so that the selected channel is shifted to a pre-defined intermediate frequency (IF), and so that an image of the selected channel is attenuated relative to the selected channel; and

(3) filtering said down-converted signal using an IF filter to pass the selected channel at said IF frequency, and to attenuate at least one of the remaining channels.

46. The method of claim 45, wherein step (2) comprises the step of mixing the RF input signal with a LO signal in said image reject mixer, wherein a frequency of said LO signal is determined based on said selected channel and said IF frequency.

47. The method of claim 45, further comprising the step of:

(4) calibrating the tuner prior to step (1) based on the selected channel.

48. The method of claim 47, wherein step (4) comprises the steps of:

(a) generating a test signal having a frequency that corresponds to the

selected channel;

(b) injecting said test signal into an input of the tuner;

(c) calibrating said input filter based on said test signal;

(d) calibrating an amplifier based on said test signal; and

(e) calibrating said image reject mixer based on said test signal.

49. The method of claim 48, wherein step (c) comprises the steps of:

(I) determining an I/Q balance of said input filter based on said test signal; and

(ii) adjusting parameters of said input filter to improve said I/Q balance for said input filter at said selected channel frequency.

50. The method of claim 48, wherein step (d) comprises the steps of:

(I) determining an I/Q balance of said amplifier based on said test signal; and

(ii) adjusting parameters of said amplifier to improve said I/Q balance for said amplifier at said selected channel frequency.

51. The method of claim 48, wherein step (d) comprises the steps of:

(I) determining an I/Q balance of said image reject mixer based on said test signal; and

(ii) adjusting parameters of said image reject mixer to improve said I/Q balance for said image reject mixer at said selected channel frequency.

52. The method of claim 51, further comprising the step of:

(iii) adjusting an I/Q balance of a local oscillator signal that drives said image reject mixer to improve said I/Q balance of said image reject mixer.

53. A method of down-converting a radio frequency (RF) signal to an intermediate frequency (IF) signal, comprising the steps of:

(1) filtering the RF signal to reject at least one out-of-band signal;

(2) in-phase (I) and quadrature (Q) mixing the RF signal with a LO signal to produce an IF signal having image suppression; and

(3) filtering said IF signal to select the desired channel.

54. The method of claim 53, wherein step (2) comprises:

(a) dividing the RF signal into a first component and a second component;

(b) mixing said first component of the RF signal with an in-phase component of said LO signal to produce an in-phase IF signal component, and mixing said second component of the RF signal with a quadrature component of said LO signal to produce a quadrature IF signal component; and

(c) combining said in-phase IF signal component and said quadrature IF signal component.

55. The method of claim 54, wherein step (c) comprises the step of combining said in-phase IF signal component and said quadrature IF signal component in an IF filter having a passband at a frequency of said desired channel.

Direct Conversion Tuner

Abstract

A direct conversion tuner down-converts television signals, cable signals, or other signals directly from an RF frequency to an IF frequency and/or baseband, without an intermediate up-conversion step for image rejection. The direct conversion tuner includes a pre-select filter, an amplifier, an image reject mixer, and a poly-phase filter. The pre-select filter, amplifier, and the image reject mixer can be calibrated to provide sufficient image rejection to meet the NTSC requirements for TV signals. The entire direct conversion tuner can be fabricated on a single semiconductor substrate without requiring any off-chip components. The tuner configuration described herein is not limited to processing TV signals, and can be utilized to down-convert other RF signals to an IF frequency or baseband.

A279-40.wpd

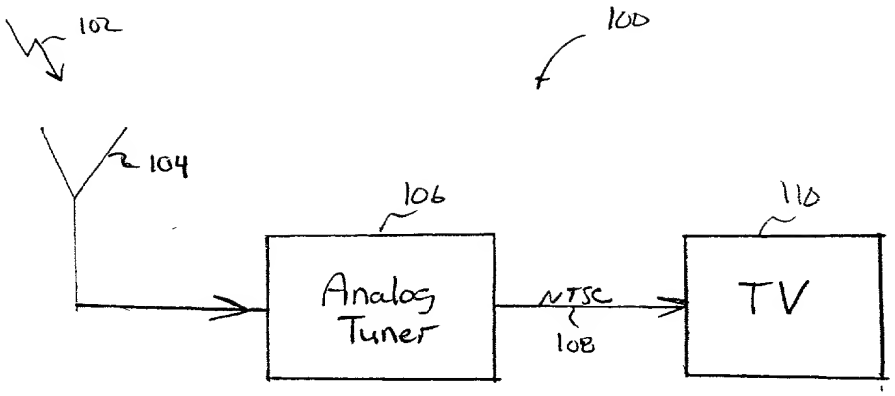
102
100
104
106
110
Analog Tuner
NTSC
108
TV

FIG. 1A

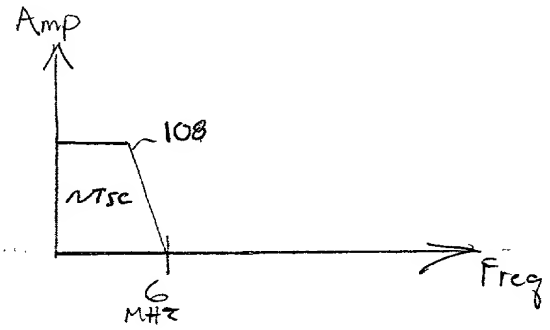
Amp
108
NTSC
6 MHz
Freq

FIG. 1B

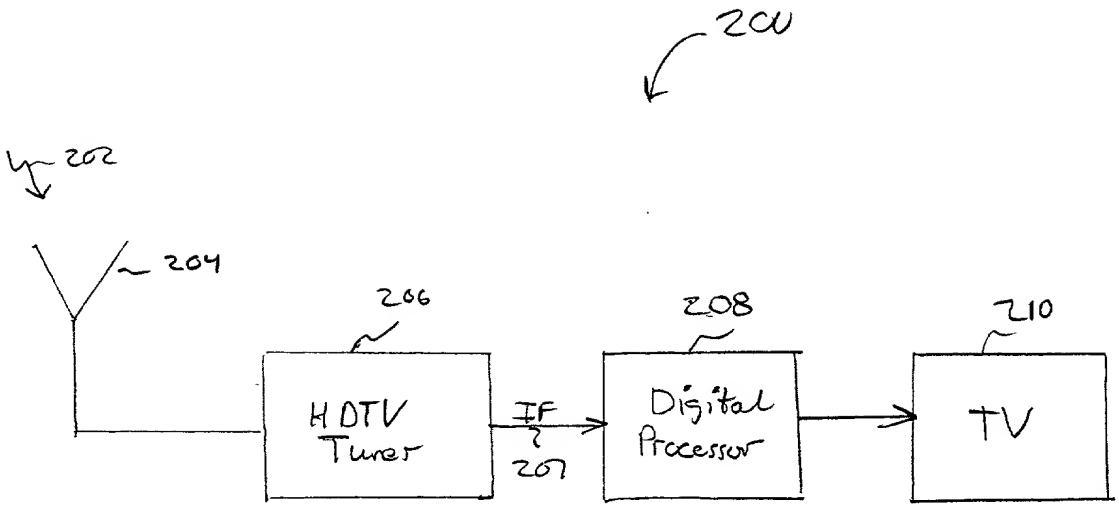
200
202
204
206
208
210
HDTV Tuner
IF
207
Digital Processor
TV

FIG. 2

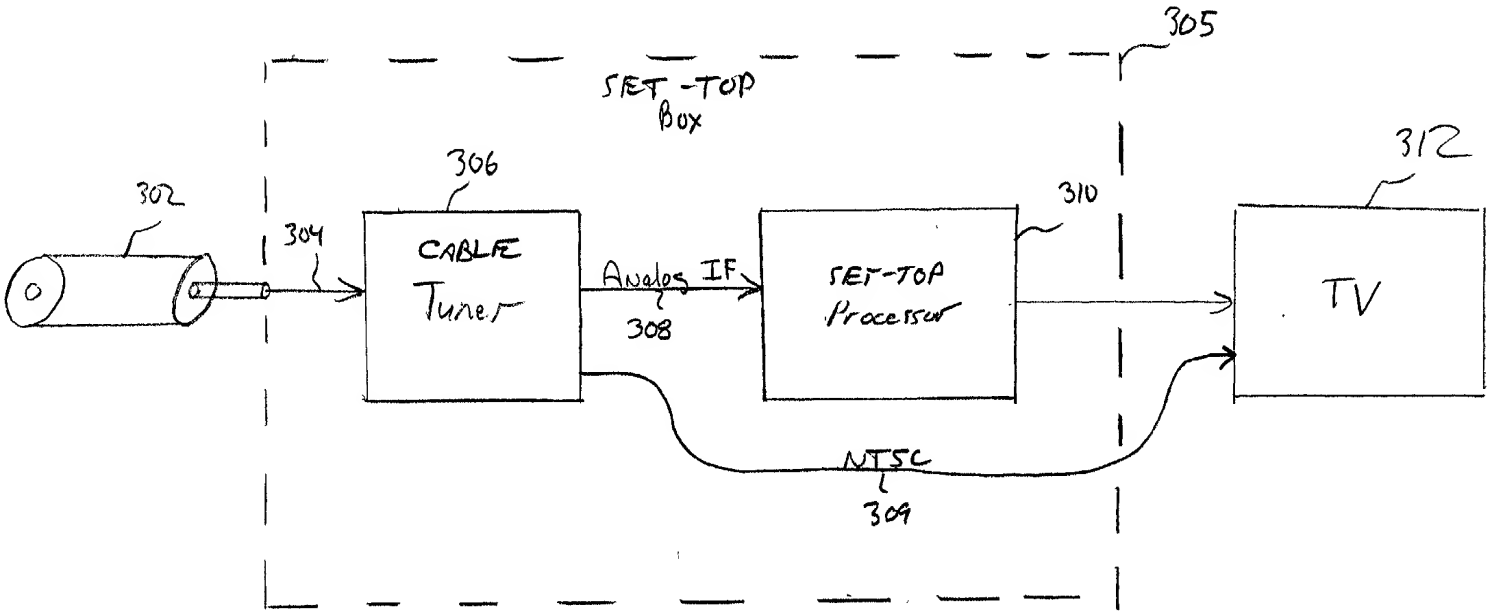
305
SET-TOP Box
312
306
302
310
304
CABLE Tuner
Analog IF
308
SET-TOP Processor
TV
NTSC
309

FIG. 3A

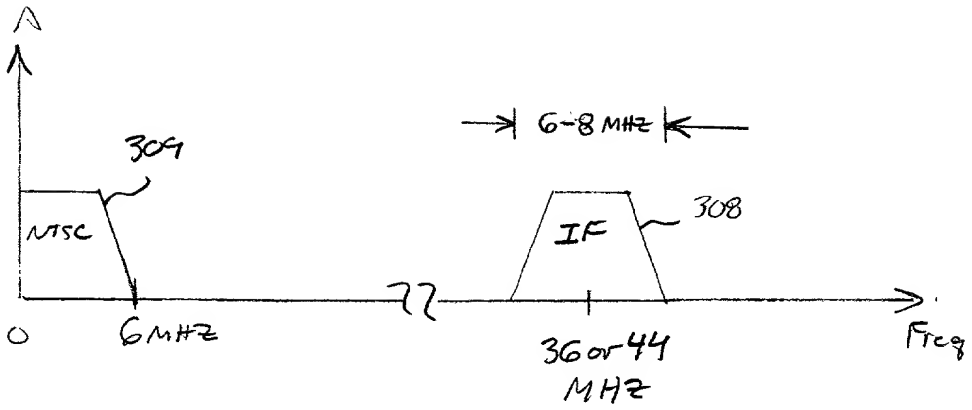

FIG. 3B

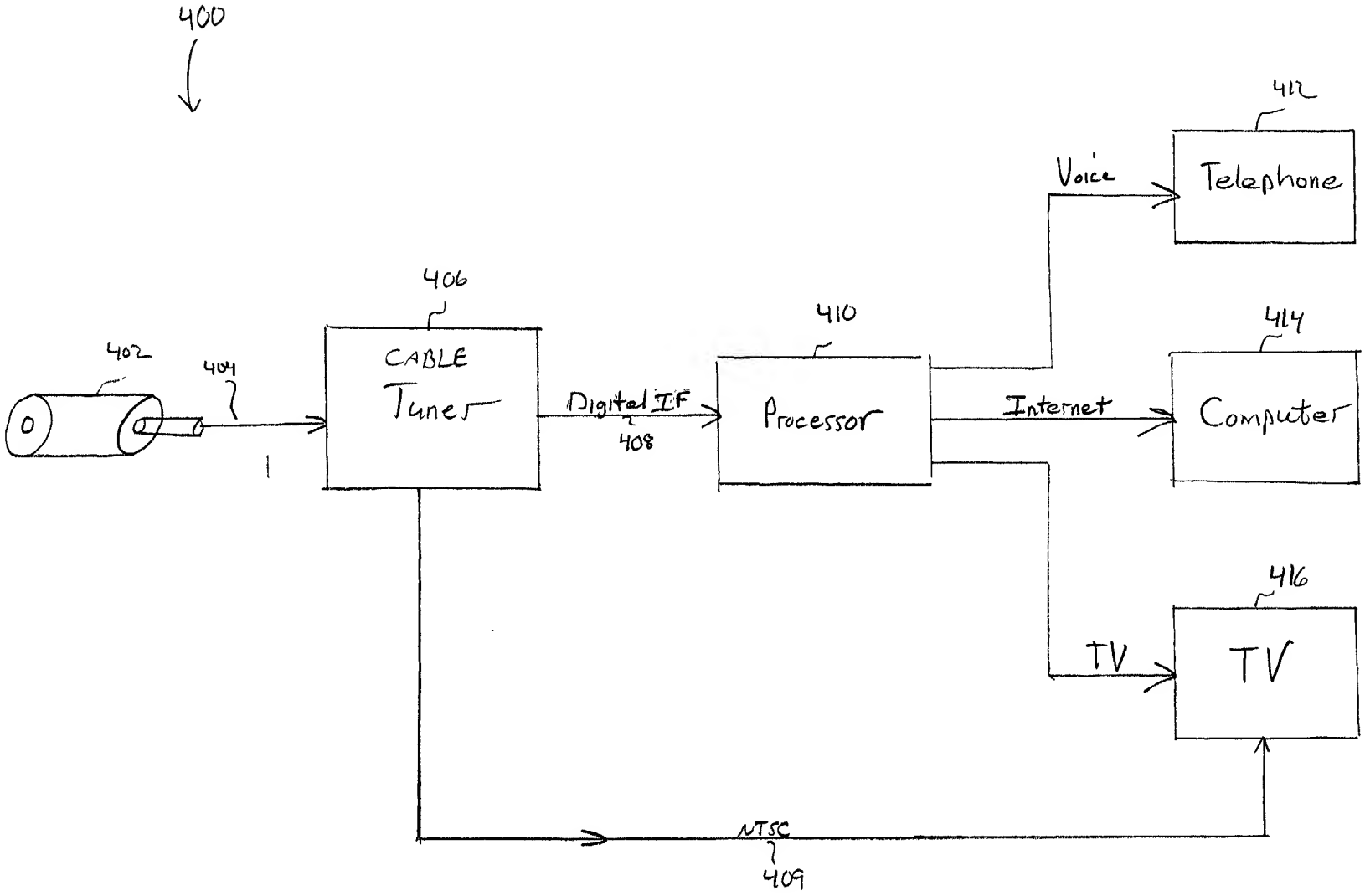
400
412
Telephone
Voice
406
CABLE
Tuner
410
414
Computer
402
404
Digital IF
408
Processor
Internet
416
TV
TV
NTSC
409

Fig. 4

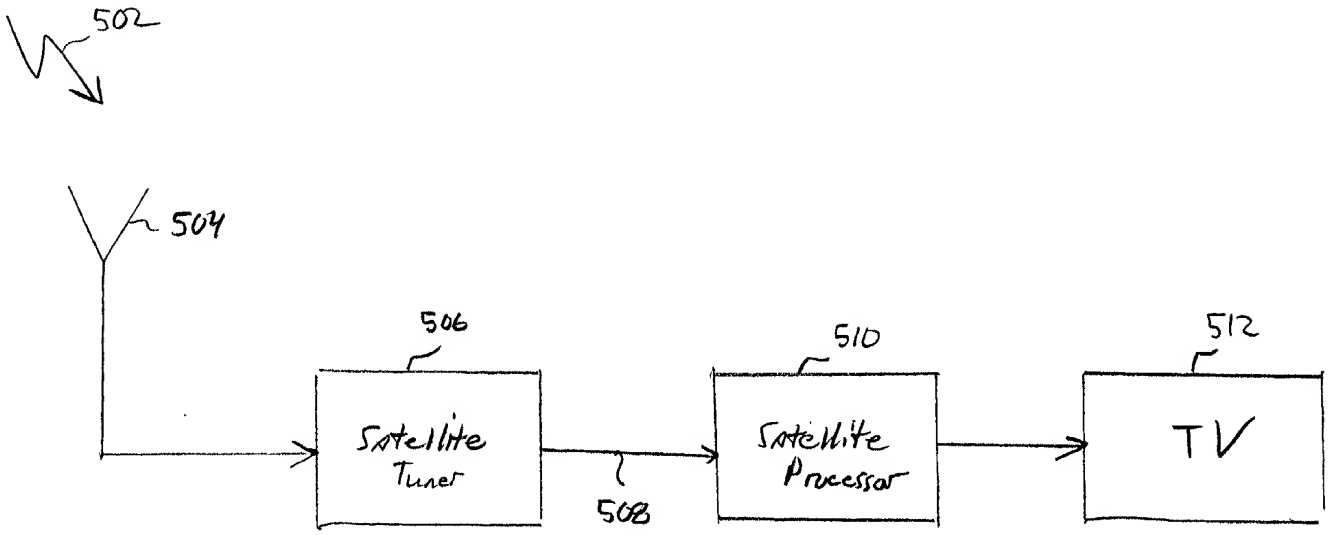
502
504
506
Satellite Tuner
508
510
Satellite Processor
512
TV

FIG. 5

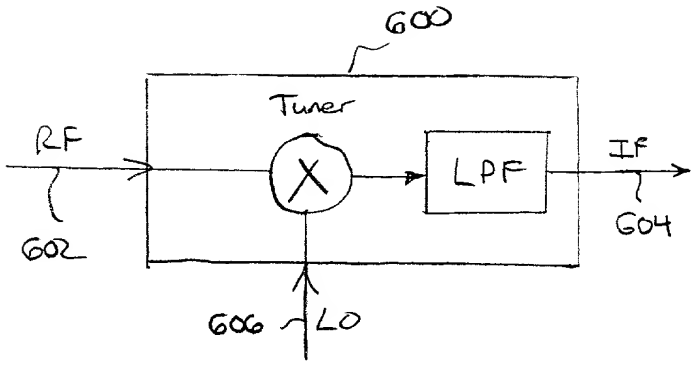
600
Tuner
RF
602
X
LPF
IF
604
606
LO

FIG. 6A.

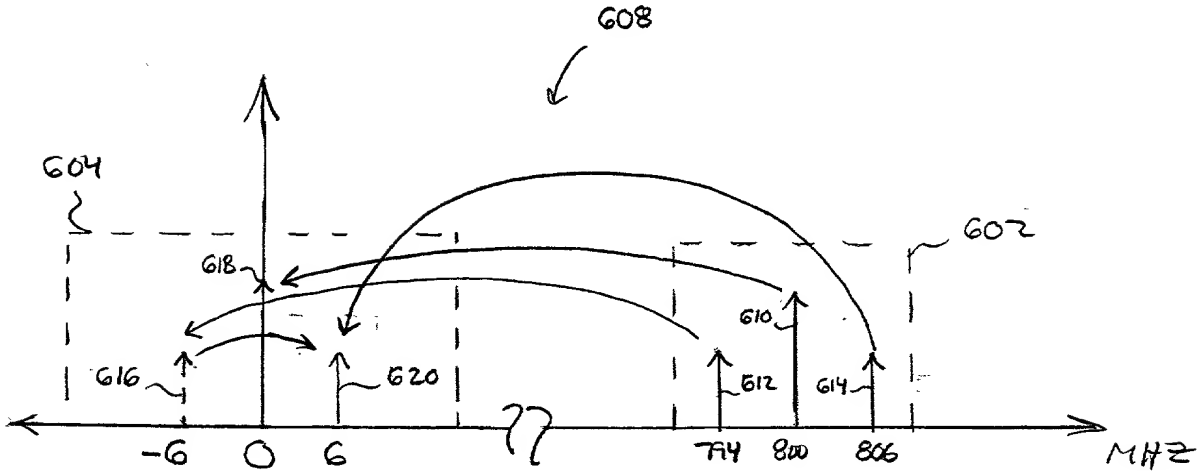
608
604
602
618
610
616
620
612
614
-6
0
6
714
800
806
MHZ

FIG. 6B

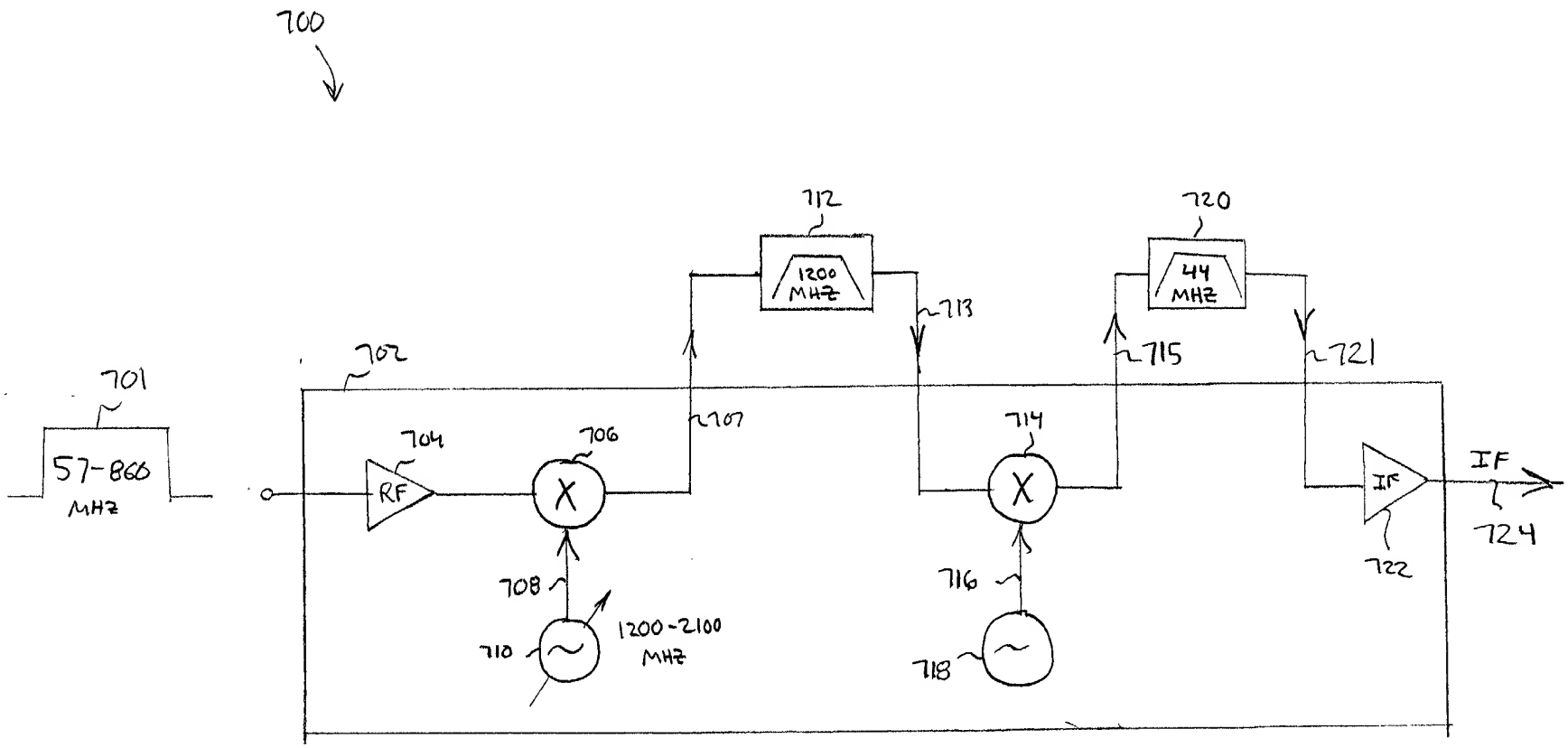
700
701
57-860
MHz
702
704
RF
706
X
707
708
710
1200-2100
MHz
712
1200
MHz
713
714
X
715
716
718
720
44
MHz
721
IF
722
IF
724

FIG. 7

US 6,101,360 A 8/2000

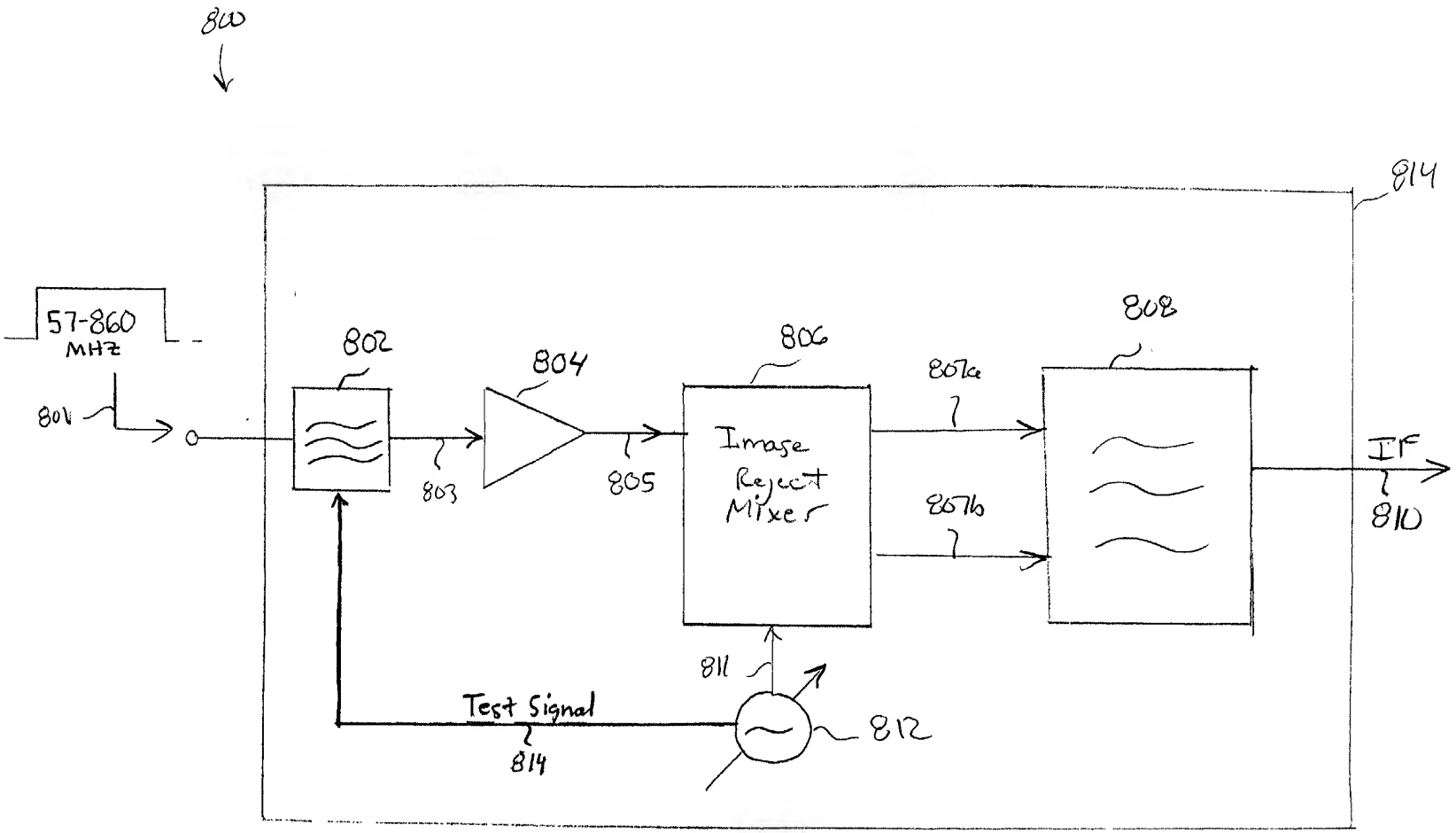

FIG. 8

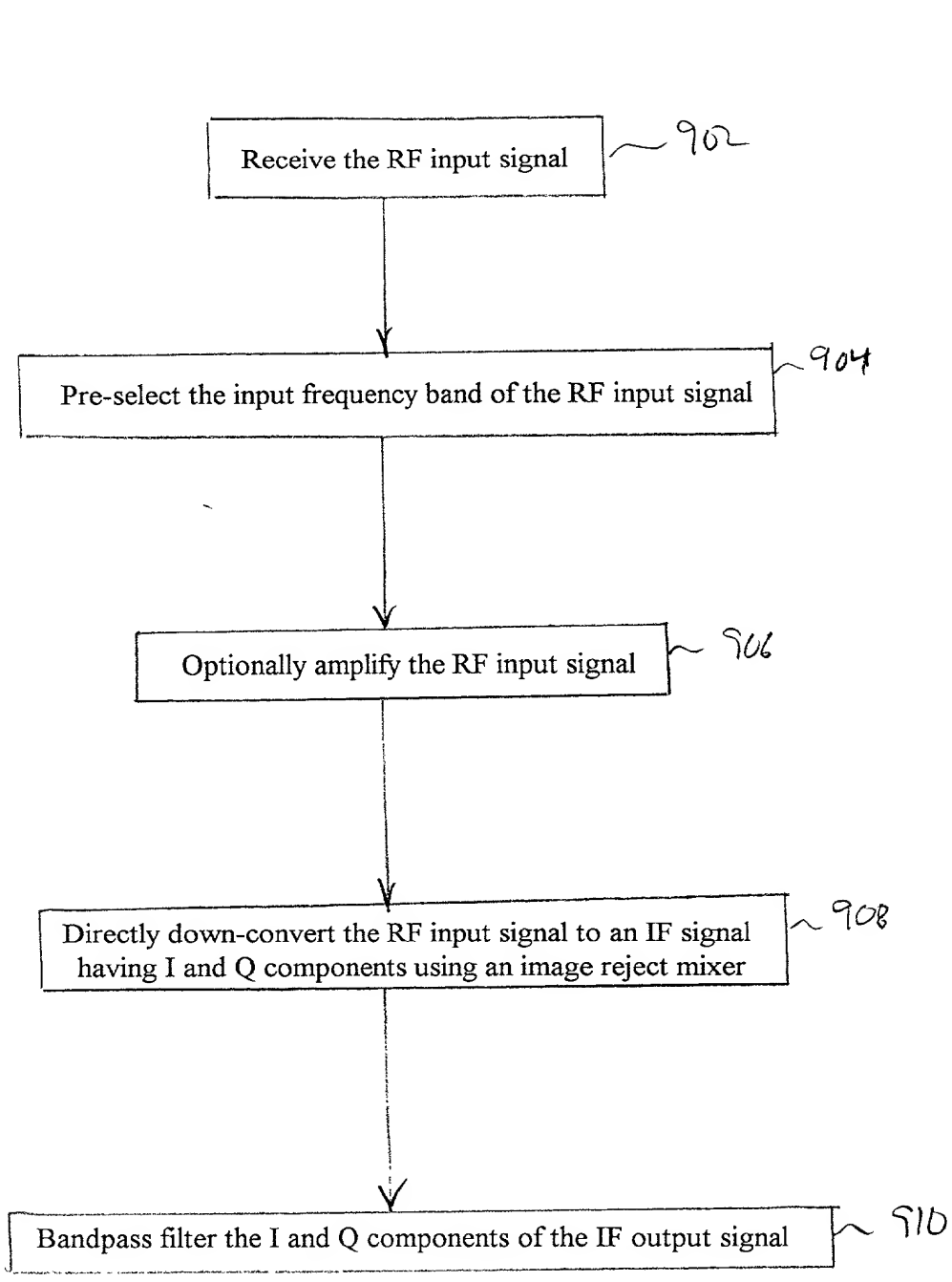
900
Receive the RF input signal
902
Pre-select the input frequency band of the RF input signal
904
Optionally amplify the RF input signal
906
Directly down-convert the RF input signal to an IF signal having I and Q components using an image reject mixer
908
Bandpass filter the I and Q components of the IF output signal
910

FIG. 9

1062

801 812 810

Channel	Channel Frequency (MHZ)	LO Frequency (MHz)	IF Frequency (MHz)
2	57	93 or 21	36
3	63	99 or 27	36
3	69	105 or 33	36
4	75	111 or 39	36
•	•	•	•
•	•	•	•
•	•	•	•
134	848	884 or 812	36
135	854	890 or 818	36
136	860	896 or 824	36

FIG. 10A

1004

801

Channel	Channel Frequency (MHZ)	LO Frequency (MHz)	IF Frequency (MHz)
2	57	101 or 13	44
3	63	107 or 19	44
3	69	113 or 25	44
4	75	119 or 31	44
•	•	•	•
•	•	•	•
•	•	•	•
134	848	892 or 804	44
135	854	898 or 812	44
136	860	904 or 820	44

812

810

FIG. 10B

DOCKET FAIRCHILD

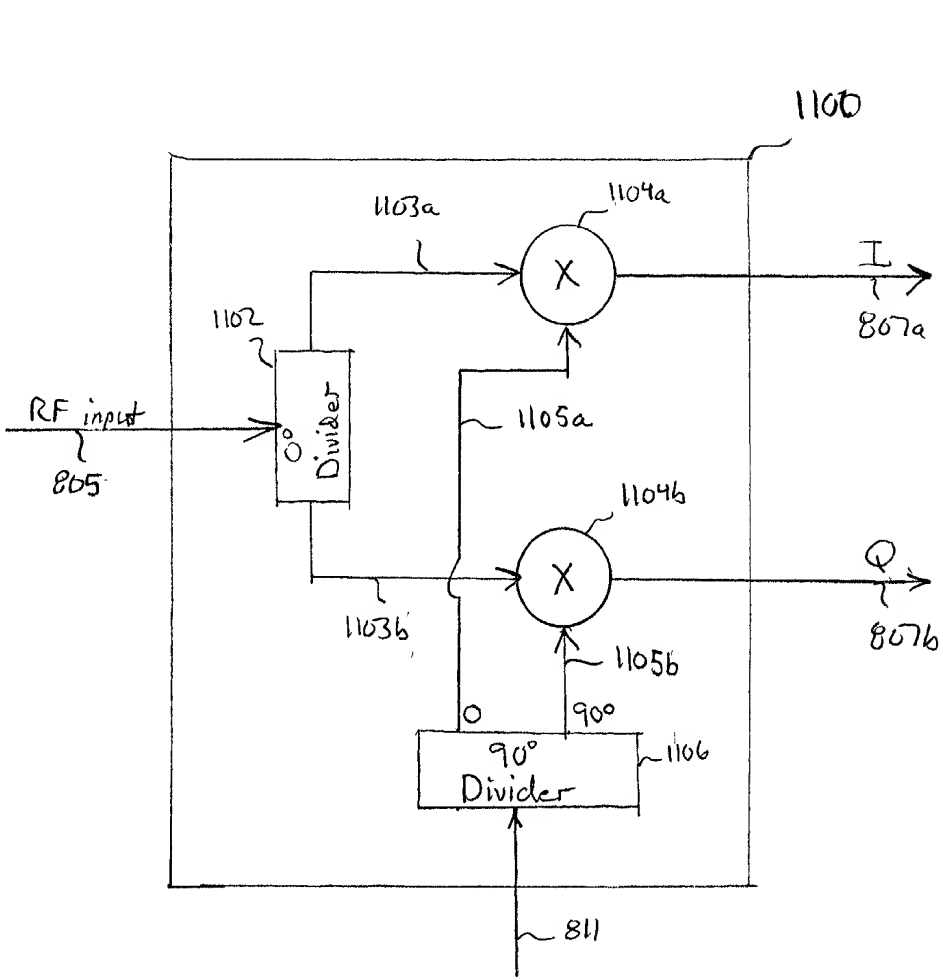

FIG. 11

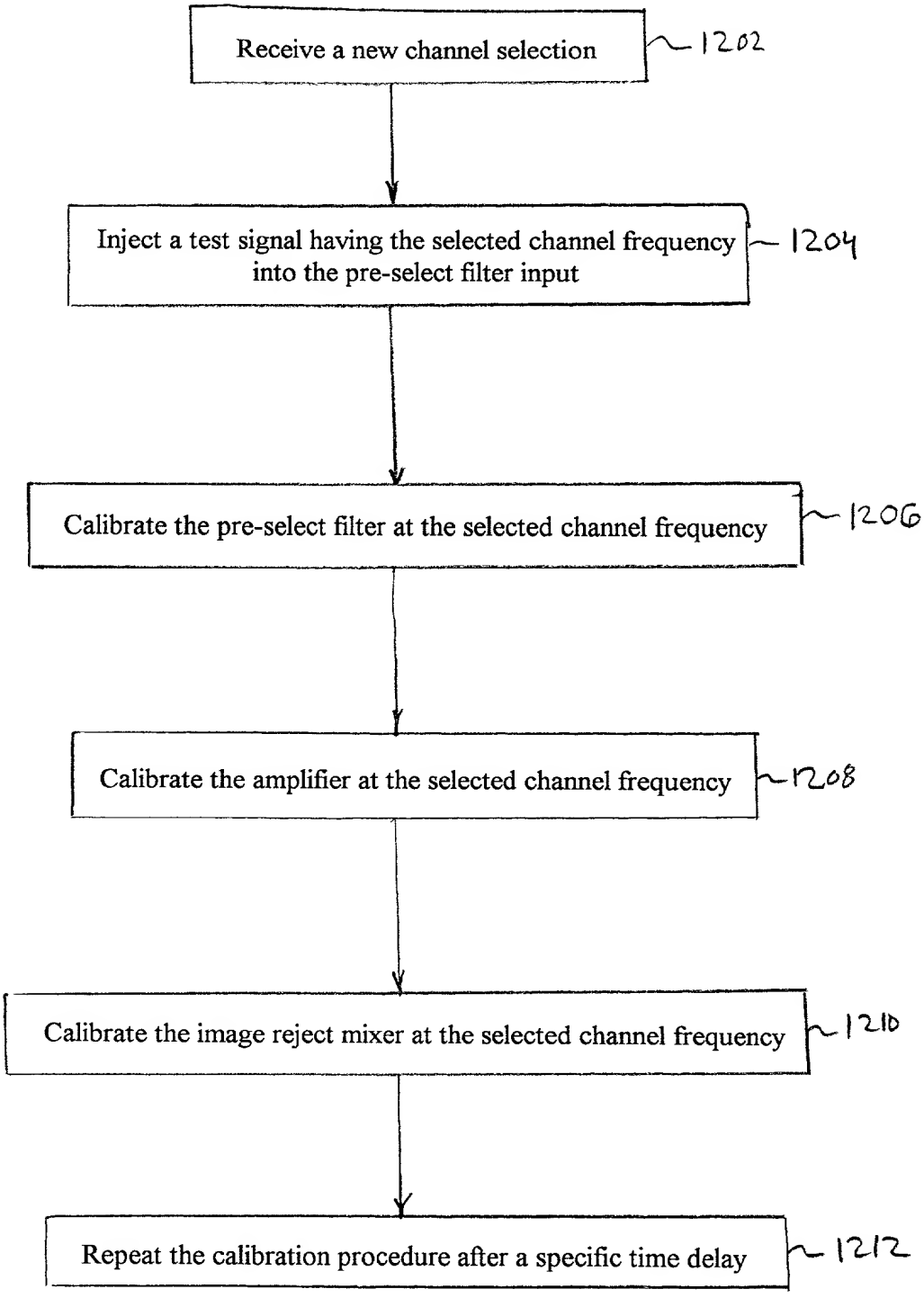
1200
Receive a new channel selection
1202
Inject a test signal having the selected channel frequency into the pre-select filter input
1204
Calibrate the pre-select filter at the selected channel frequency
1206
Calibrate the amplifier at the selected channel frequency
1208
Calibrate the image reject mixer at the selected channel frequency
1210
Repeat the calibration procedure after a specific time delay
1212

FIG. 12

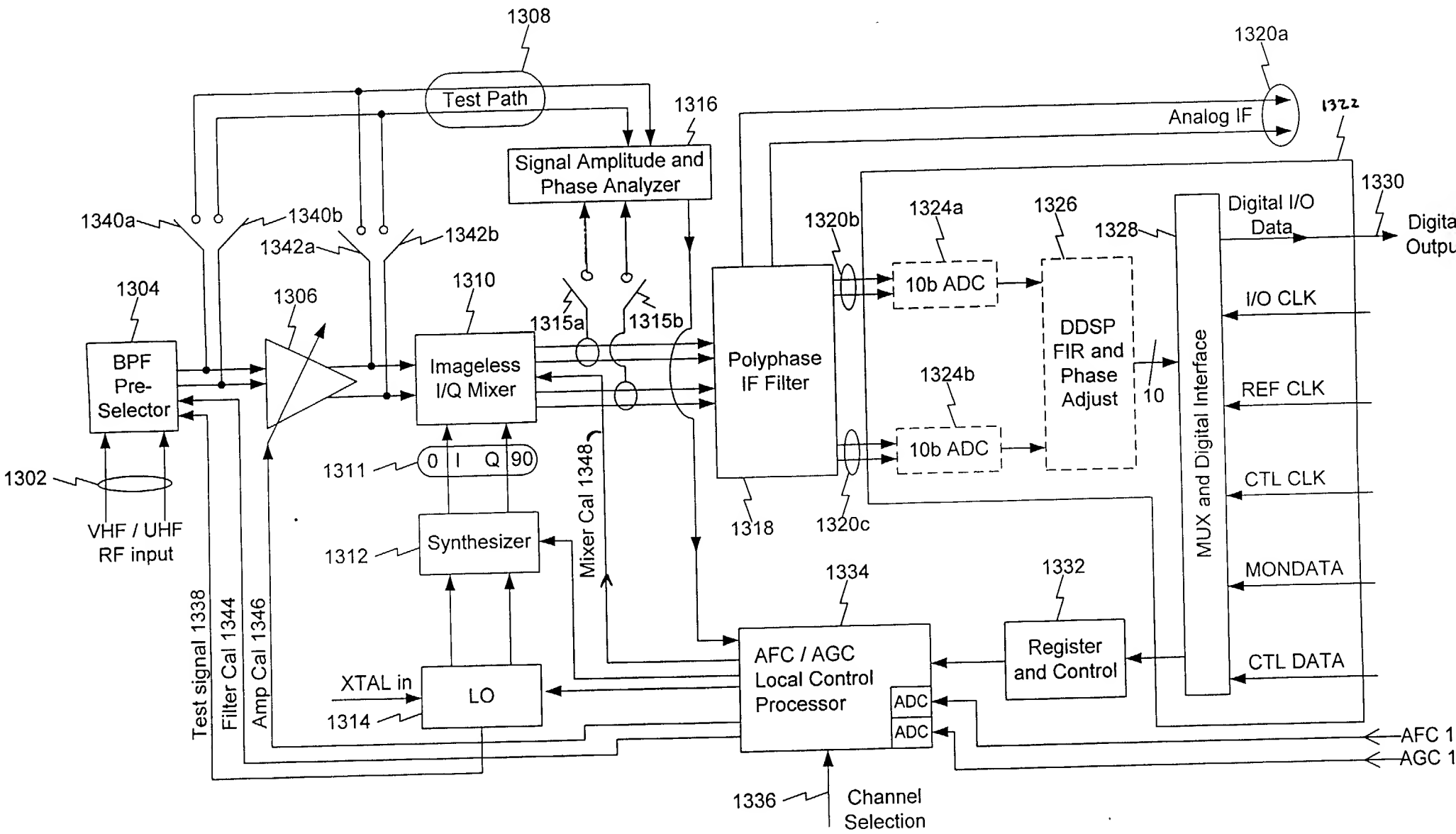

FIG. 13

1300

0003-34

SCANNED

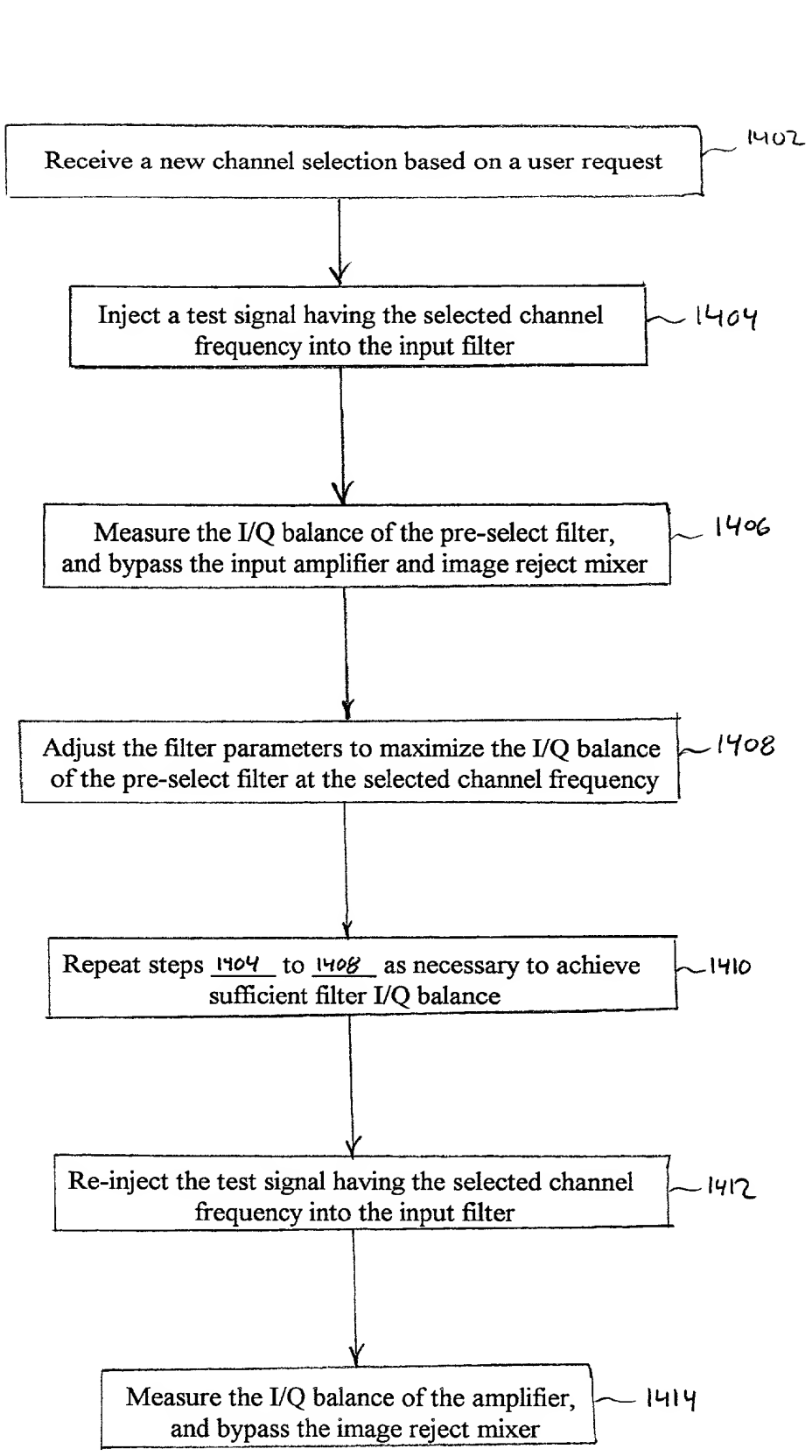
1400
Receive a new channel selection based on a user request
1402
Inject a test signal having the selected channel frequency into the input filter
1404
Measure the I/Q balance of the pre-select filter, and bypass the input amplifier and image reject mixer
1406
Adjust the filter parameters to maximize the I/Q balance of the pre-select filter at the selected channel frequency
1408
Repeat steps 1404 to 1408 as necessary to achieve sufficient filter I/Q balance
1410
Re-inject the test signal having the selected channel frequency into the input filter
1412
Measure the I/Q balance of the amplifier, and bypass the image reject mixer
1414

FIG. 14A

1400 (cont.)

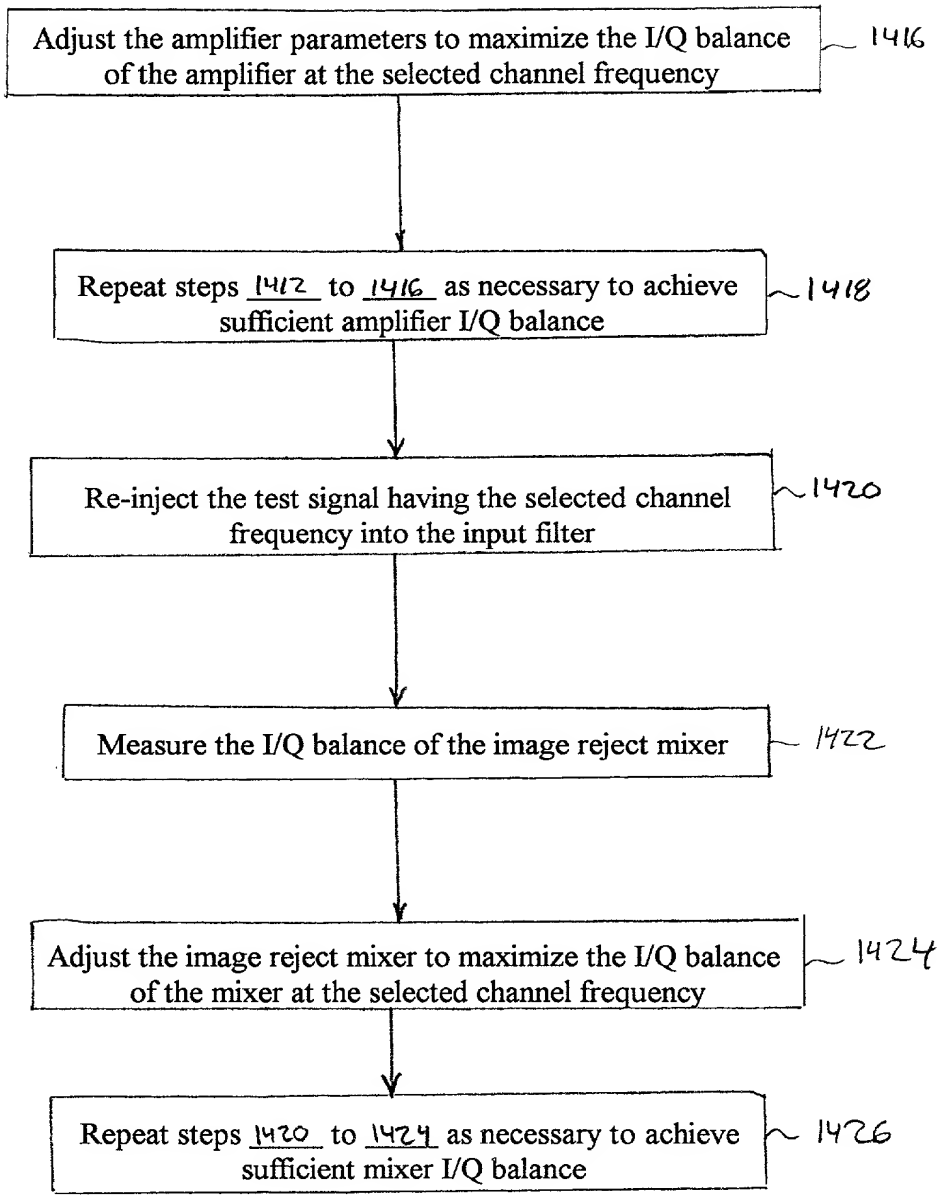

FIG. 14B

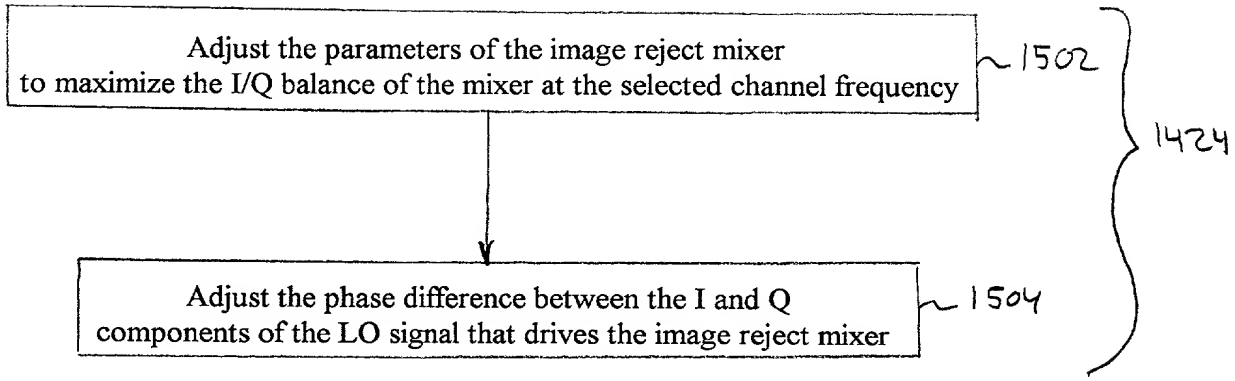
1500
Adjust the parameters of the image reject mixer to maximize the I/Q balance of the mixer at the selected channel frequency
1502
Adjust the phase difference between the I and Q components of the LO signal that drives the image reject mixer
1504
1424

FIG. 15

0083600 T6535950

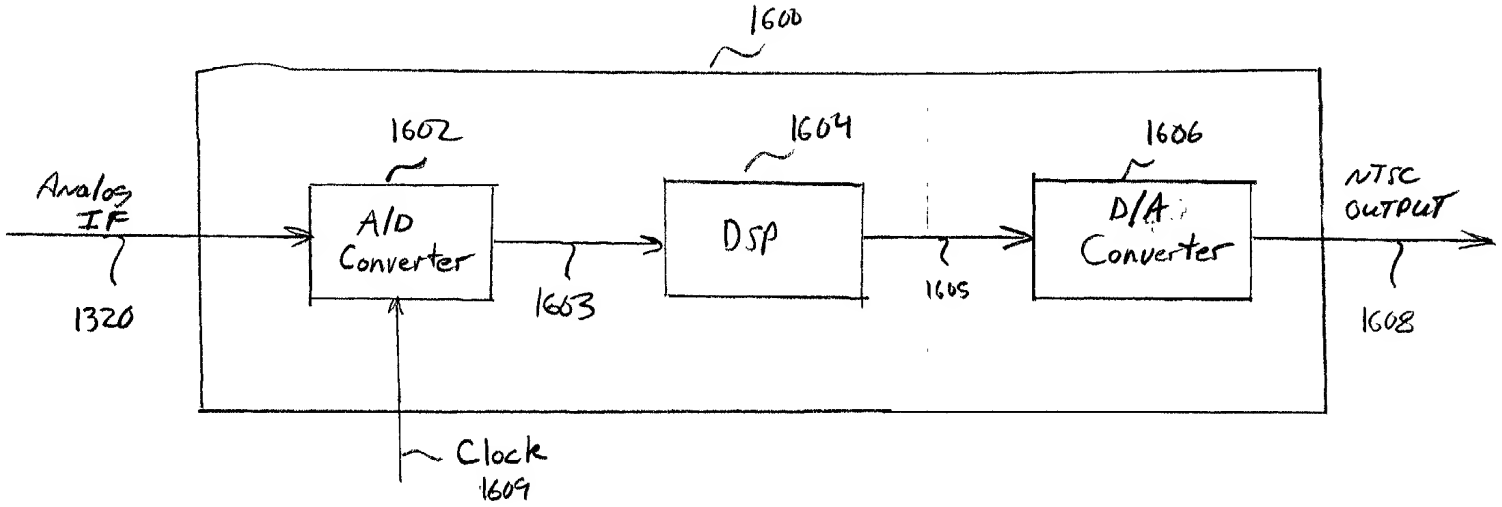

FIG. 16